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The TAT-12/13 Cable Network

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The TAT-12/13 Cable Network, when completed in September 1996, will provide 10 Gb/s of fully in-network restorable capacity between the United States, the United Kingdom, and France.

On December 16, 1992, representatives of 45 telecommunication carriers from 34 countries met in Paris to sign an agreement to construct a new undersea cable network linking North America and Europe. This new network was named Transatlantic Telephone (TAT)-12/13 and continued the tradition started in 1953 when AT&T and the British Post Office agreed to build the first TAT cable. Like the previous 11 TAT cables, the TAT-12/13 Network is to provide telecommunication services between points in or reached via the United States and points in or reached via the United Kingdom and France. Specifically, this network is to meet the capacity needs of the signing carriers through 2006 in a cost-effective manner. In addition, this network is to provide "in-network" restoration of itself and make this restoration capability available for the restoration of other cable systems in the Atlantic region.

To manage the entire project within the budget of $740 million, the consortium of carriers formed a procurement group consisting of representatives from AT&T, British Telecom (BT), and France Telecom to determine network requirements and negotiate supply contracts. This article describes the network and its capabilities.

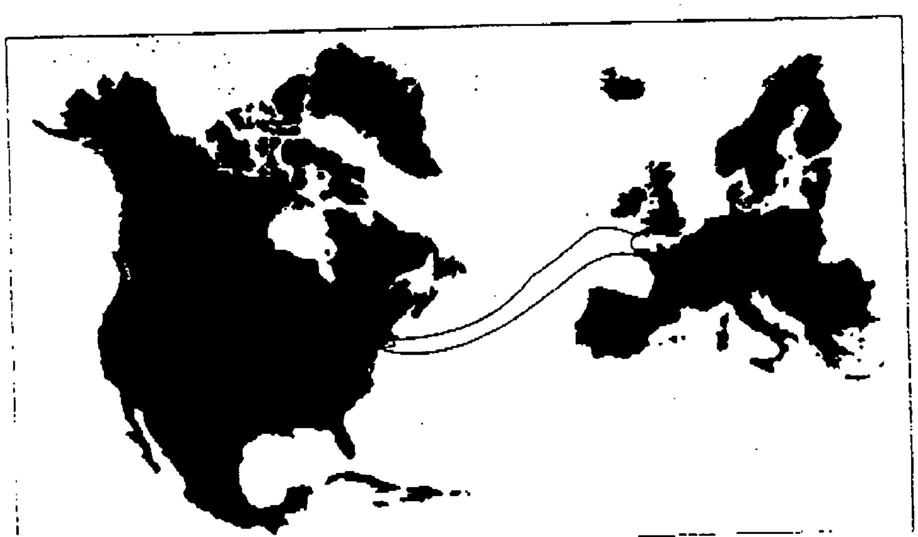
The Network Route

Figure 1 shows a map of the TAT-12/13 Network. The network consists of a ring of undersea cable segments interconnecting cable stations in Green Hill, Rhode Island, United States; Lands End, England; Penmarc'h, France; and Shirley, New York, United States. The undersea cable segment between Green Hill, Rhode Island, and Lands Ends, England, was supplied jointly by STC Submarine Systems and AT&T Submarine Systems, Inc. (SSI). It is 5913 km long, of which 3759 km was supplied by STC and 2154 km by AT&T-SSI. The segment has 133 repeaters spaced every 45 km that make use of optical amplifier technology (to be described later). This segment was installed in the summer of 1995 and is now carrying traffic.

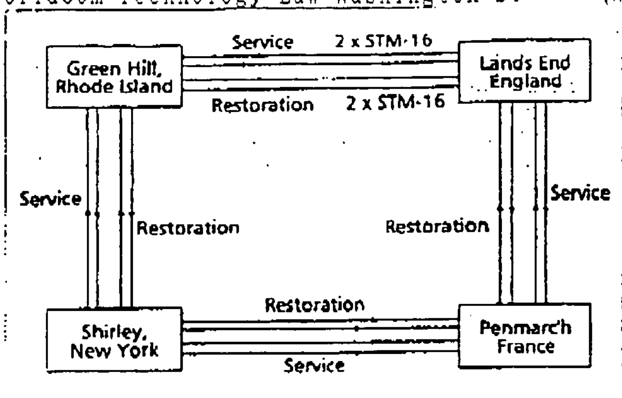
The undersea cable segment between Lands End, England, and Penmarc'h, France, was supplied by Alcatel Submarcom. It is 370 km long and contains four undersea optical amplifier repeaters spaced 74 km apart. It was installed in the spring of 1995 and is now carrying traffic.

The undersea cable segment between Shirley, New York, and Green Hill, Rhode Island, was supplied by AT&T-SSI. It is 162 km long and contains no undersea repeaters. It makes use of high-power optical amplifiers in the terminal station equipment enabling traffic to traverse the entire segment without undersea amplification. It was installed in the fall of 1994 and is now carrying traffic.

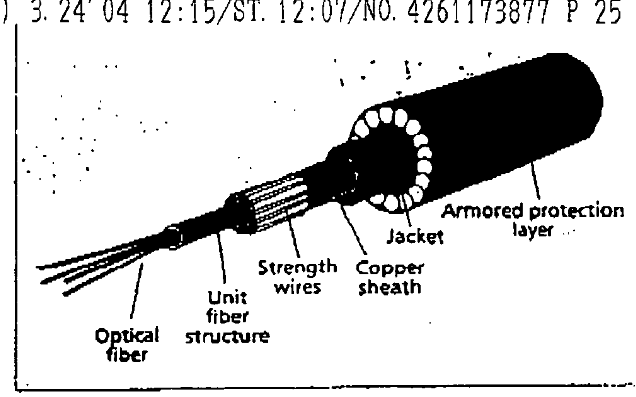
The undersea cable segment between Penmarc'h, France, and Shirley, New York, is supplied jointly by AT&T-SSI and



■ Figure 1. *The TAT-12/13 Cable Network.*



■ Figure 2. *TAT-12/13 Network configuration.*



Alcatel Submarcom. It is 6321 km long and contains 140 optically amplified repeaters spaced every 45 km, where 4127 km is supplied by AT&T-SSI and 2194 km by Alcatel. This segment is being installed now and, when completed in the spring of 1996, will complete a ring of undersea cable around the North Atlantic Ocean.

By the end of September 1996, the TAT-12/13 Network will be capable of carrying up to 10 Gb/s of traffic that is fully restorable *within* the network. By using ring switching equipment supplied by Toshiba Corporation in each of the four cable stations, traffic is automatically rerouted in the opposite direction around the ring to bypass a fault in any of the undersea segments. This rerouting takes place quickly enough that service will not be interrupted, making failures transparent to the network users.

The Network Configuration

Figure 2 shows the network configuration. Each cable segment contains two fiber pairs. One fiber pair is designated *service* and the other pair *restoration*. In the normal mode of operation, when all four cable segments are fault-free, traffic is carried on the service fiber pairs. Each service fiber pair transports two STM-16s (2.5 Gb/s) at a bit rate of 5 Gb/s, allowing for a total capacity of four STM-16s (10 Gb/s) between the United States and Europe over the two transatlantic cables.

There is also 10 Gb/s of capacity on the restoration fiber pairs. In the normal mode of operation, the restoration fiber paths could be used to carry what might be considered "lower-priority traffic." This traffic could be either restoration traffic from another cable system or traffic that the telecommunication carriers deem interruptable.

Any traffic on the restoration pairs would automatically be dropped should a fault on the service pairs be detected. The restoration pairs would then be used as the path to reroute the service traffic via the opposite direction of the ring. Traffic switching takes place in less than 300 ms, ensuring uninterrupted service.

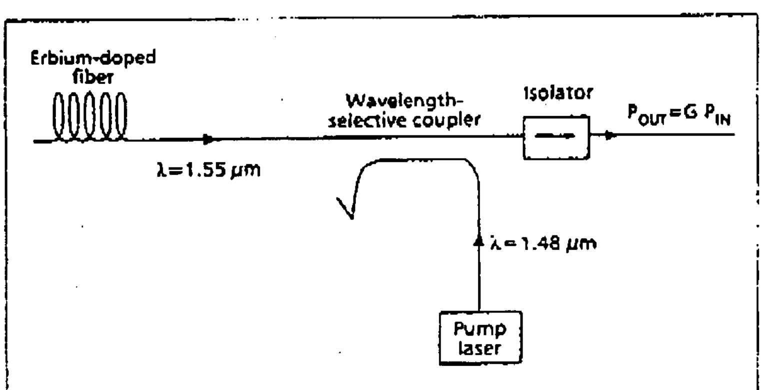
The Submerged Equipment

The submerged equipment consists of cables and repeaters. For this network, several types of cable are being used with the purpose of protecting the four glass fibers traversing the ocean bottom. The cable to be used in water depths less than 1000 m is armored and buried for protection against ships' anchors and fishing activity. Figure 3 shows a diagram of one type of armored cable.

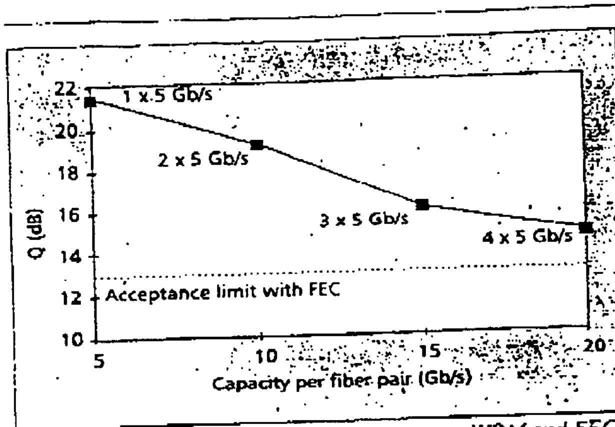
The undersea repeaters contain new optical amplifier technology that is changing the entire transmission system industry. Erbium-doped fiber amplifiers (EDFAs) are simple devices that amplify light power. A low-power optical signal enters the amplifier, and a high-power optical signal exits. Figure 4 shows a diagram of an EDFA. The incoming transmission fiber is spliced to a short length (about 10 m) of erbium-doped fiber. This specially doped fiber has the property of amplifying 1.55-μm signal light when "pumped" with laser light of a particular wavelength, in this case 1.48 μm. Light from the pump laser is coupled (in this case in the counter-propagating direction) into the erbium-doped fiber using an optical coupler. Amplified signal power exits the erbium-doped fiber with more optical power (and, unavoidably, with added amplified spontaneous emission noise). An optical isolator is then used to prevent reflected light from propagating (and being amplified) in the counter-propagating direction. The EDFA is a simple yet effective device with properties that make it the most significant development in optical communications since the development of low-loss optical fiber.

The repeaters in the TAT-12/13 undersea segments each contain two pairs of unidirectional amplifiers, one pair for each fiber pair. For the transatlantic segments the amplifiers provide about 10 dB of power gain. For the England-to-France segment the repeater gain is about 16 dB to allow for greater repeater spacing.

Note that the optical fibers and the optical amplifiers within the repeaters can propagate and amplify several wavelengths of light signals simultaneously, and that each of these signals can have different bit rates. Therefore, the submerged



■ Figure 4. *Erbium-doped fiber amplifier.*



■ **Figure 5.** *TAT-12/13 upgrade potential using WDM and FEC.*

plant of TAT-12/13 can be thought of as four optical pipes that encircle the North Atlantic Ocean. These pipes have been designed to be reliable enough to last 25 years, and because of the technology used (namely, optical fiber with optical amplifiers), they have the potential to keep pace with the growth of international telecommunication services.

Contrast this with the TAT-8 Cable System, which has been in service since 1988. TAT-8 was the first TAT system to use optical fibers. The undersea repeaters, however, contain electro-optic regenerators. These regenerators operate at a fixed bit rate and cannot be changed. Although designed for 25 years of operation, the traffic-carrying capacity of just 280 Mb/s on each of two fiber pairs between the United States and Europe will make TAT-8 technologically obsolete well before 2013.

By using optical amplifiers in the submerged repeaters, the traffic-carrying capacity of TAT-12/13 is only limited by the initial system design and the availability of more advanced terminal station equipment. For example, the transoceanic segments of TAT-12/13 have been designed to transport a single 5 Gb/s optical signal on each fiber pair. Repeater spacing and dispersion maps were chosen to accomplish this objective. However, due to new developments, experience, and knowledge, ways to exploit the enormous transport capacity of these installed optical pipes may allow TAT-12/13 to be upgraded when more transatlantic capacity is needed.

This upgrade potential has already been demonstrated. Figure 5 shows results of transmission experiments done on an installed portion of TAT-12/13 [1]. The results show that by using a combination of wavelength-division multiplexing (WDM) and forward error correction (FEC), it is possible to increase the transport capacity of TAT-12/13 to 10 Gb/s, 20 Gb/s, and possibly higher on each fiber pair. Of course, to make use of these technologies significant changes would be needed in the cable station equipment. The submerged plant, however, would remain untouched.

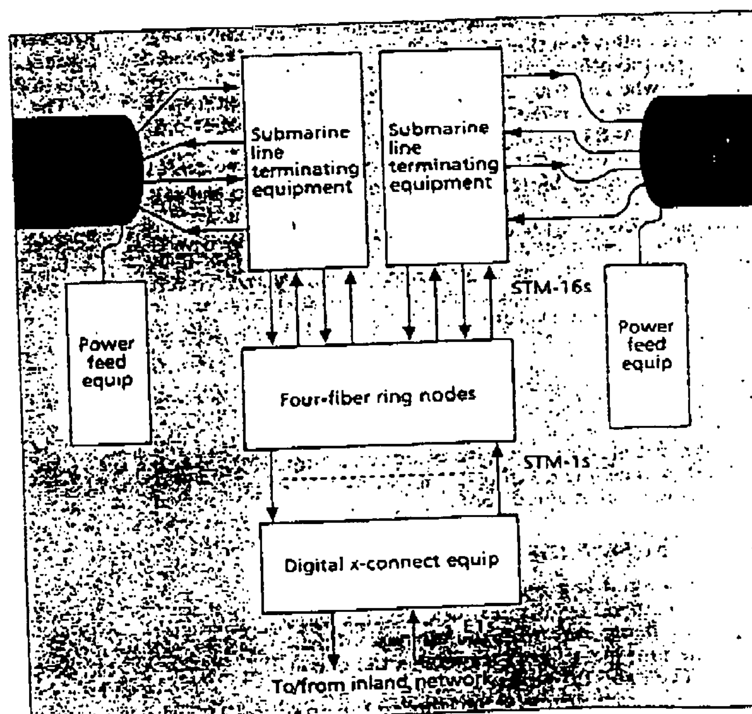
The Equipment in the Cable Stations

Located in each of the four cable stations is equipment that accesses the submerged plant and the inland networks of the telecommunication carriers. Figure 6 shows a block diagram of the interconnections of this equipment at one of the cable stations.

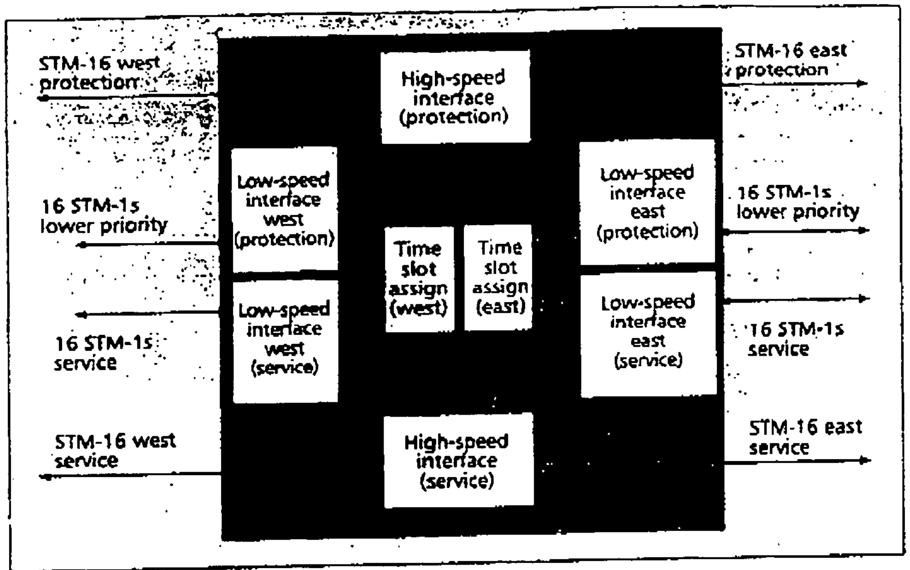
Power feed equipment (PFE) supplies electrical power to the repeaters over the copper conductor in the undersea cable. TAT-12/13 PFE supplies a constant current of 1.6 A through the cable where the sea is the return conductor. About 5000 V is needed from the PFE on each side of the transatlantic segments. Each set of PFE contains redundant equipment so that service outages due to failures within the PFE sets are limited.

Submarine line terminating equipment (SLTEs) contains the 5 Gb/s transmitters and receivers and the interleaving equipment to combine two optical STM-16 signals into a 5 Gb/s optical signal suitable for transmission over 6500 km of undersea cable. Each set of SLTE contains fully redundant hardware and automatic protection switching equipment to ensure that outages due to SLTE circuit pack failure are limited. Monitoring equipment is attached to the SLTE to provide for in-service monitoring and out-of-service fault location of the submerged plant.

Four-fiber ring nodes (FFRNs) supplied by Toshiba Corporation perform the multiplexing of the STM-1 (155 Mb/s) signals into the STM-16 optical signals to be sent to the SLTEs. There are two FFRNs in each of the four stations of the TAT-12/13 Network. Figure 7 shows a block diagram of an FFRN. Up to 64 STM-1s are connected to each FFRN. To designate to which of the four STM-16s an STM-1 is assigned, the STM-16s are labeled "west"-bound service and protection and "east"-bound service and protection. The westbound STM-16s are associated with the undersea cable segment that terminates at the cable station, and the eastbound STM-16s are associated with the other undersea cable segment terminating in that cable station. Note that the eastbound/west-



■ **Figure 6.** *Block diagram of equipment at cable stations.*



■ Figure 7. *Block diagram of four-fiber ring node.*

bound designation has nothing to do with the actual geographical direction. Furthermore, designating STM-16s service means that switching will be done in order to ensure that traffic assigned to these STM-16s is maintained. Designating STM-16s protection means that switching will be done to move the traffic from the service STM-16s to the protection STM-16s. Traffic ordinarily carried on the protection STM-16s is dropped whenever switching is done to maintain service traffic flow. The FFRN switching protocol operates according to the International Telecommunications Union (ITU) Recommendations for transoceanic line switched rings. See the article in this issue on the TPC-5 cable network for a more detailed description of ring switching.

A digital access and cross-connect system (DACS) provides access ports to the telecommunication carriers. All signals entering the DACSs must be made up of virtual connection (VC)-12 signals or 2 Mb/s signals (E1s) which are then mapped into VC-12 signals. The DACSs then groom the VC-12s, placing them into STM-1s to be sent to the FFRNs for routing over the undersea cables.

Network Integration

One of the major challenges in constructing TAT-12/13 was the integration of the various network elements from four suppliers: Alcatel, STC, AT&T-SSI, and Toshiba. In order for interface specifications to be finalized and to ensure proper interfacing of the installed network, a series of laboratory tests were carried out during the summer of 1994 in Freehold, New Jersey. Here, equipment prototypes from each of the suppliers were tested with each other to ensure network compatibility. Results showed that traffic could be restored in less than 300 ms in the event of a cable cut.

Network Performance, Reliability, and Availability

TAT-12/13 Network error performance at the STM-1 level meets the relevant ITU Recommendation G.826 for errored blocks, errored seconds and severely errored seconds. This level of error performance corresponds to a bit error rate of better than 4×10^{-10}.

TAT-12/13's reliability is projected to be less than one ship repair needed over 25 years due to undersea component failures. TAT-12/13, like previous TAT systems, will have this high level of reliability as a result of extensive component qualification and certification. An even higher level of reliability than previous systems is expected because of fewer active components being used in optical-amplifier-based repeaters.

For service providers, circuit availability is what really determines how reliable a network is. Poor availability results when service-affecting failures occur in cable station equipment. Circuit availability is also impacted when a cable is accidentally cut by fishing trawlers or ship anchors. For TAT systems, a decreased number of cable faults has been realized by armoring and burying the shallow water ends of the undersea cables. TAT-12/13 makes use of extensive experience in cable installations throughout the North Atlantic by armoring and burying the TAT-12/13 cables until the water depth is more than 1000 m.

Even with armor protection and cable burial, accidental cuts still occur. However, with the use of ring switching equipment and diverse routes, the availability of 10 Gb/s of capacity on TAT-12/13 is designed to be 100 percent under single-fault conditions. That is to say, by using two cables across the Atlantic and fast switching technology, no traffic outage is expected over the design life of TAT-12/13 for the traffic that is routed over the service fiber pairs. To achieve 100 percent availability, diligent in-service maintenance and monitoring of the equipment will be required to ensure that preventable outages do not occur.

Traffic Routing

The purpose of the TAT-12/13 Network is to carry traffic for international telecommunications service providers. This is ordinarily done as a series of bilateral agreements between carriers operating on each side of the ocean.

To describe this further, let us take the case of one such bilateral agreement between AT&T and BT. AT&T and BT agree to jointly own and operate several minimum investment units (MIUs) of TAT-12/13. For TAT-12/13, an MIU is a bidirectional E1 (2 Mb/s) channel, in this case between the cable stations in Green Hill, Rhode Island, and Lands End, England. This channel can be used to carry 30 64 kb/s circuits or whatever configuration the carriers chose. For example, with speech interpolation equipment it is possible to fit 150 voice circuits into the 2 Mb/s data stream. Other carriers having ownership of TAT-12/13 have similar bilateral agreements for MIUs between the cable stations.

E1s access the cable stations via inland digital carrier systems. These could be via asynchronous or synchronous transport systems. In any case, the E1s access the DACS and are placed into the STM-1s for transport. An STM-1 can carry 63 E1s. The groomed STM-1s are sent from the DACS to the ring nodes for routing over the undersea cable segments. The ring nodes combine 16 STM-1s to form an STM-16, and the STM-16 is sent optically to the SLTEs, where they are combined with another STM-16 from another ring node to form a

5 Gb/s optical signal for transport over the undersea cable segments.

SUMMARY

The TAT-12/13 Network, when completed in September 1996, will transport 4032 E1s between the United States, the United Kingdom, and France. By using ring switching equipment, this capacity is fully restorable within the network without dropping calls in the process.

The undersea repeaters in this network use optical amplifier technology to transport a single 5 Gb/s optical signal on each fiber pair. With the upgrade potential already demonstrated, TAT-12/13's transport capacity may at least double before the end of its 25-year design life.

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BIOGRAPHIES

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JOHN ARENA is responsible for the project management of the network protection system for the TAT-12/13 Cable Network. Since joining AT&T Bell Labs in 1984 as a member of technical staff, he has worked on various aspects of international telecommunciations. He holds a Bachelor's degree in electrical engineering